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METHOD FOR DETERMINING THE ROTOR POSITION OF A SYNCHRONOUS MOTOR

The present invention relates to a method for determining the rotor position of a synchronous motor. Such a method can be necessary, for example, to start a synchronous motor that is monitored by a position-measuring instrument which only delivers unequivocal commutation signals after a reference position has been overtravelled.

From the related art, numerous methods are known by which it is possible to determine the position of the rotor of a synchronous motor in order to permit the electrical commutation of the motor, even without position information from a position-measuring instrument. Many of these methods are based on complicated measurements of the inductances of the primary-circuit coils or the measurement and evaluation of the electromotive counterforce. Such methods make it possible to operate a synchronous motor completely without a position-measuring instrument.

If for the start-up or when putting the synchronous motor into operation, the desire is merely to determine the rotor position, for instance, to determine an offset between the position-measuring instrument and the rotor, or to operate the motor to a reference point, then simpler methods are sufficient for determining the rotor position. Of importance for the operation of a synchronous motor is actually the position of the vector of the magnetic moment of the rotor, but in simplified terms, the position of the rotor is spoken of in the following.

EP 1 085 650 A2 describes a method, according to which initially a first motor phase is energized. Based on the resulting movement direction of the rotor, it is possible to

electrically pin down the rotor position to an angular range of 180°. If a second phase which is situated centrally in this range is then energized, the rotor position can be electrically pinned down to an angular range of 90° based on the resulting direction of rotation of the rotor. With each further step, this range is halved, so that the method can be aborted when the desired exactitude has been achieved. The disadvantage in this method, however, is that relatively large movements of the rotor must be brought about before the resulting direction of rotation can be unequivocally detected with the aid of a position-measuring instrument. If these movements are selected to be too small, then grooving forces and machine vibrations can lead to a false result; the rotor position is then no longer correctly detected. However, larger movements are problematic and are not allowed in all cases, for instance, when a synchronous motor is driving a tool that is already engaged with a workpiece. Another disadvantage of this method is that the current necessary for generating a movement of the rotor becomes increasingly greater, the narrower the angular range becomes. Namely, if the magnetic field generated by the current vector is already nearly parallel to the rotor, then, given a constant current, the torque generated becomes increasingly smaller. The accuracy of the method is thus limited by the maximum possible current.

The object of the present invention is to indicate a simple method by which it is possible to determine the rotor position of a synchronous motor.

This objective is attained by a method as recited in Claim 1. Advantageous details of the method are revealed by the claims dependent on Claim 1.

In most cases, it is advisable to initially lock the rotor of the synchronous motor using a brake. Such a brake is already available in many applications, for instance, in machine tools

where, for safety reasons, electrical and mechanical motor brakes are customary for all axes. The holding force of such a brake is great compared to grooving forces of the synchronous motor or forces applied to the rotor by machine vibrations. These effects are therefore insignificant for the subsequent determination of the rotor position; it is thus possible to work with very small deflections of the rotor, which are still allowed even in critical applications. If the synchronous motor is held by a great static friction, even without a brake, then the engagement of a brake may be needless, since the static friction ultimately acts like an engaged brake.

In order to move the rotor of a synchronous motor, a current which generates a magnetic field vector must be generated in the coils of the synchronous motor. The magnetic field provides for a torque at the rotor if the rotor is not magnetically parallel (stable equilibrium) or antiparallel (unstable equilibrium) with respect to the field vector. When a current vector is mentioned in the following, it has the amount of the impressed current and the direction of the magnetic field generated by the current. All angle specifications specific to the rotor of the synchronous motor relate in the following to one electrical period, i.e. one full rotation of the current vector. In a synchronous motor, one full rotation of the motor shaft may definitely correspond to a plurality of electrical periods.

If with the brake engaged, a plurality of current vectors having a different angular position are now applied to the synchronous motor, and for each of these current vectors, the amount is determined that is necessary to attain a small defined deflection of the rotor against the holding force of the brake, a curve shape results having two minima which are situated, offset in each case by 90°, before and after the sought angle of the rotor position. Thus, the rotor position is already established with the determination of one minimum

of the current necessary for attaining a defined deflection, and the motor can be started in controlled fashion if, additionally, the direction of the deflection is taken into consideration in this minimum. This is because a maximum torque is achieved at a constant current when the rotor and current vector are aligned perpendicularly to one another. A required defined deflection is achieved here using a minimum current. Conversely, the generated torque is very small at a given current when the current vector and the rotor are nearly parallel or antiparallel. Thus, to attain a defined deflection, a suitably high current will be necessary. However, the present invention is based precisely on determining the position of the rotor from the angular positions with minimal amount of the current vectors; the measurement of the amount of the current vector necessary for attaining a defined deflection can thus be broken off when the current reaches a limiting value, without the accuracy of the rotor-position determination thereby suffering.

In the first approximation, a force proportional to the deflection is necessary for deflecting a motor held by a brake. This can be attributed, for example, to the elasticity of the shaft with which the rotor and the brake engage. However, the holding force of the brake itself may also be viewed as spring force for very small deflections. A restoring force proportional to the deflection of the rotor or a restoring moment proportional to the deflection results. If one measures the amount of the current vector necessary for attaining a defined deflection, this defined deflection corresponds precisely to a defined torque. Instead of a position-measuring instrument for measuring the deflection of the rotor, the method could thus also be carried out using a torque sensor by which it is possible to determine the amount and direction of the torque of the synchronous motor. After the current vector has been switched off, the rotor returns to its original position due to the restoring moment.

Further advantages of the present invention and details pertaining thereto are derived from the following description of a preferred specific embodiment on the basis of the figures, in which

Figure 1 shows a block diagram of a drive unit having a synchronous motor;

Figure 2 shows a phasor diagram with current vector and rotor position;

Figure 3 shows the angle-dependent characteristic of the current-vector amount necessary for attaining a small deflection of the rotor.

Figure 1 shows a drive unit having a synchronous motor 2 that is triggered via a control 1. The rotor position of synchronous motor 2 is monitored via a position-measuring instrument 3 that, for example, may be an incremental rotary transducer that only allows the calculation of absolute position values after a reference point has been overtravelled. Position-measuring instrument 3 is connected to shaft 4 of synchronous motor 2. Since shaft 4 is rigidly connected to the rotor of synchronous motor 2, it is possible to infer the position of the rotor from the position of shaft 4. If necessary, a brake 5 may act upon shaft 4. Such mechanical or electrical brakes 5 are usually used to quickly brake movements in case of emergency or to keep suspended axles in the de-energized state. Brake 5 may be activated via control 1. A payload 6 is driven via shaft 4. For instance, this may be the tool spindle of a machine tool, or also a linear axle of the machine tool that is driven via a spindle.

Figure 2 shows a vector diagram in which rotor R (i.e. the vector of the magnetic moment of rotor R), without restriction of the generality, stands at 180° within an electrical period of the synchronous motor. In the exemplary embodiment

described, a current vector I is now rotated in steps of five degrees from angle $\alpha = 0°$ to $\alpha = 355°$. In so doing, for each angular position, the amount of current vector I is determined that is necessary to attain a defined deflection of rotor R. The direction in which the deflection takes place is also registered. This information may be queried by position-measuring instrument 3, in the same way as the amount of the instantaneous deflection.

In the case shown in Figure 2, rotor R is deflected clockwise, thus in the mathematically negative direction. This holds true for all current vectors I in the angular range $0° < \alpha < 180°$. In the range $180° < \alpha < 360°$, rotor R is deflected counter-clockwise, thus in the mathematically positive direction.

A few thousandths of a degree suffice as a defined deflection. Such a small deflection of less than 0.01° will scarcely have a safety-relevant significance, and may even be used when, by this deflection, a tool is moved that is engaged with a workpiece.

If one plots the amount of current vector I needed for attaining a defined deflection of rotor R against the angular position of current vector I, one obtains the curve shape shown in Figure 3. Since the resulting torque is a function of the sine of the angle between current vector I and rotor R, and the deflection of rotor R is proportional to the torque, one obtains a curve shape that is proportional to the amount of the reciprocal value of the sine of the angle between current vector I and rotor R. This function has two minima that are situated, offset by 90°, before and after the sought-after angle of rotor R. In addition, the above-described direction of the deflection of rotor R is indicated with "-" and "+" in Figure 3.

To determine the rotor position, the position of the minima is ascertained. Already with the knowledge of the position of one of the minima and the direction of the deflection, the position of rotor R is known and it is possible to start synchronous motor 2 in controlled fashion.

To increase the accuracy, taking into account the direction of the deflection, the average value of the angle of one minimum with negative direction of rotation and the succeeding (larger) angle of one minimum with positive direction of rotation is calculated by forming the sum of the two angles and halving it. The resulting angle corresponds to the sought-after position of rotor R within one electrical period. If the direction of the deflection is not taken into consideration, it is possible to obtain as the rotor position, a result shifted by 180° with respect to the actual rotor position.

Based on this result, it is now possible to carry out the commutation of synchronous motor 2 in a manner enabling a controlled start-up. To this end, it is sufficient to know the position of rotor R with an accuracy of 10° within an electrical period. If position-measuring instrument 3 reaches a reference position, thus control 1 knows the position of the rotor exactly, then the commutation may be undertaken based on the position data of position-measuring instrument 3.

As can be seen in Figure 3, in regions in which rotor R and current vector I are nearly parallel or antiparallel, no amounts of current vector I are ascertained. In these regions, a particularly high current is necessary to attain a defined deflection, since the sine of the angle between current vector I and rotor R becomes very small. However, the ascertainment of the amount of current vector I may be broken off as of a limit current without impairing the exactness of the rotor-position determination, since only the determination of the angular position of the minima of the curve shape

according to Figure 3 is important for calculating the rotor position. For this purpose, it is sufficient to record a few values in the region of these minima. Thus, the impressed current may remain relatively small.

The method described is suitable for rotary synchronous motors, the same as for linear synchronous motors. The vector representation of rotor R and current vector I in one electrical period for linear motors does not differ from that of the rotary synchronous motor. The defined deflection in the case of a linear motor is a linear deflection which generates a restoring force. For example, this deflection may be in the range of a few μm, in any case less than 0.1 mm, so that the method is in turn usable in safety-related critical applications, as well.

Suitably equipped control 1, a numerical control of a machine tool, for instance, advantageously takes over the sequencing control for the method described here.